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Washington, DC, USA
July 7 - 12, 2018

Decomposing Complex Problems Using Influential Attribute Network Graphs

Garret Fitzpatrick & Ian Monk
Shell TechWorks

www.incose.org/symp2018

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This **[report]** contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this **[report]**, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. All forward-looking statements contained in this **[report]** are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's 20-F for the year ended December 31, 2015 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward looking statements contained in this **[report]** and should be considered by the reader. Each forward-looking statement speaks only as of the date of this **[report]**, **[*09 JUL 2018*]**. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this **[report]**.

We may have used certain terms, such as resources, in this **[report]** that United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov.

Authors

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Ian Monk is a Product Owner for Shell. Ian has eight years of industry experience across varying engineering disciplines in the oil and gas, defense, and aerospace industries. Ian earned a bachelor's degree in Mechanical Engineering from Worcester Polytechnic Institute and a master's degree in Systems Architecting and Engineering from the University of Southern California.

Garret Fitzpatrick

Garret Fitzpatrick is the Head of Products at Shell TechWorks. He has 14 years of experience in a variety of systems engineering and project management roles in the aerospace and energy industries. Previously, he worked at the NASA Ames Research Center as the Lead Project Engineer on a cell biology payload for the International Space Station. He also worked at the NASA Johnson Space Center as a Crew Escape Engineer and Hardware Manager for the Space Shuttle Program. Garret earned a bachelor's degree in Engineering Mechanics and Astronautics at the University of Wisconsin-Madison and a master's degree in Science Writing at the Massachusetts Institute of Technology.

Shell TechWorks

Created to fill a gap in Shell's R&D supply chain

Barriers:

- Annual budget cycles
- "Because we've always done it this way"
- Layered decision-making
- Reliance on vendors

- Direct business funding
- Fresh perspective from outside oil & gas
- Agile and entrepreneurial culture
- Tech pull vs. tech

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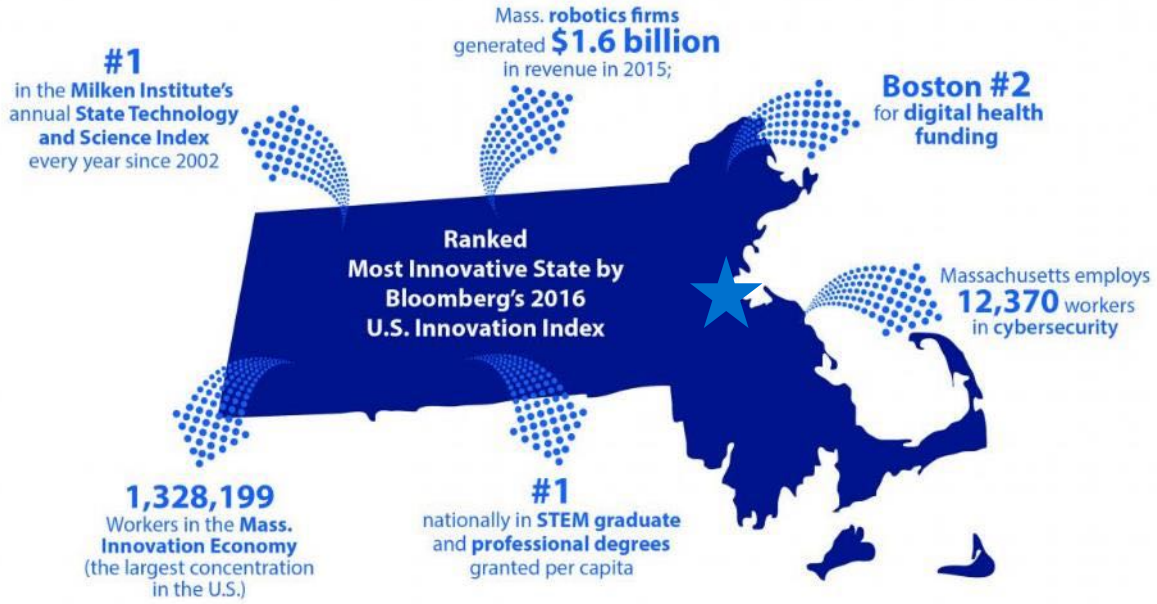

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THE ENGINE Built by MIT · Microsoft · PHILIPS · Google · Shire · IDEO · BOSE · CIC · Pfizer · facebook · GE · ANALOG DEVICES · AMGEN · SAINT-GOBAIN · IBM · Fidelity INVESTMENTS · AUTODESK · twitter · Johnson & Johnson · BROAD INSTITUTE · MASSACHUSETTS CLEAN ENERGY CENTER · PTC · nationalgrid · Biogen · DRAPER · SANOFI · amazon · Volpe

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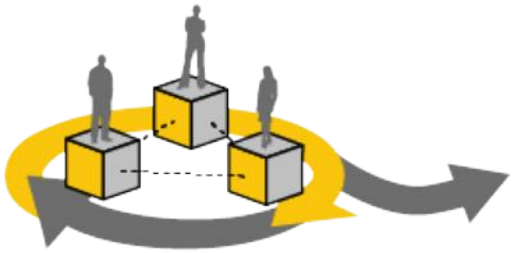
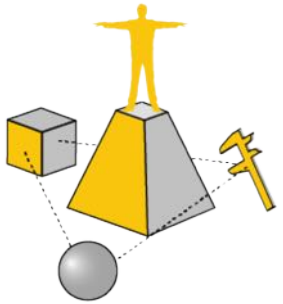
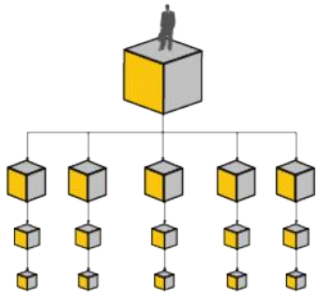


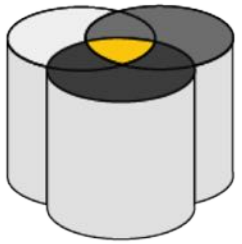
Agile Management



T-shaped Skills



Systems Engineering



Robust Ecosystem

Bringing an outside perspective to Shell's toughest challenges

DEFENSE

DRAPER
QinetiQ
BAE SYSTEMS
MITRE
Raytheon

ENERGY

Oak Ridge
SIEMENS
AMBRI
BraytonEnergy
ExxonMobil
NUVERA
TOTAL
GENERAL COMPRESSION
GMZ ENERGY
NOV

CONSUMER PRODUCTS & MEDICAL

FedEx
Honeywell
PRECISION BIOSCIENCES
Newell Rubbermaid
HAEMONETICS
BOSE
cytonome

AEROSPACE

NASA
Orbital
TEXTRON
SCALED COMPOSITES
BOEING
Aurora FLIGHT SCIENCES
LOCKHEED MARTIN

ROBOTICS

HYDROID
A KONGSBERG COMPANY
HARVEST AUTOMATION
KIVA Systems
GENERAL DYNAMICS Robotic Systems, Inc.
symbotic
amazon

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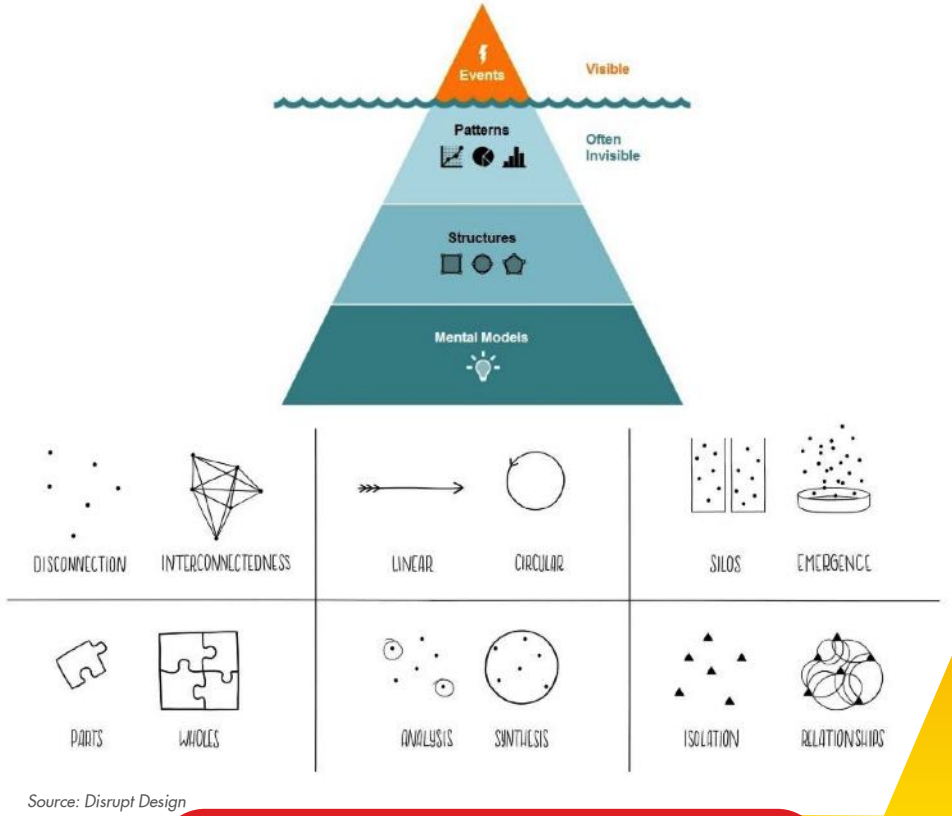


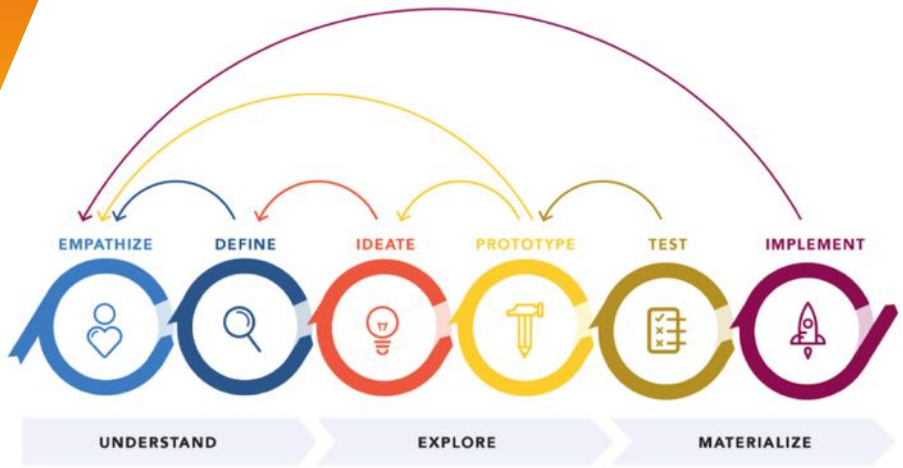
Source: Disrupt Design

Systems Thinking

- *Holistic, sum > parts*
- *Interfaces & feedback loops*
- *Problem-based*

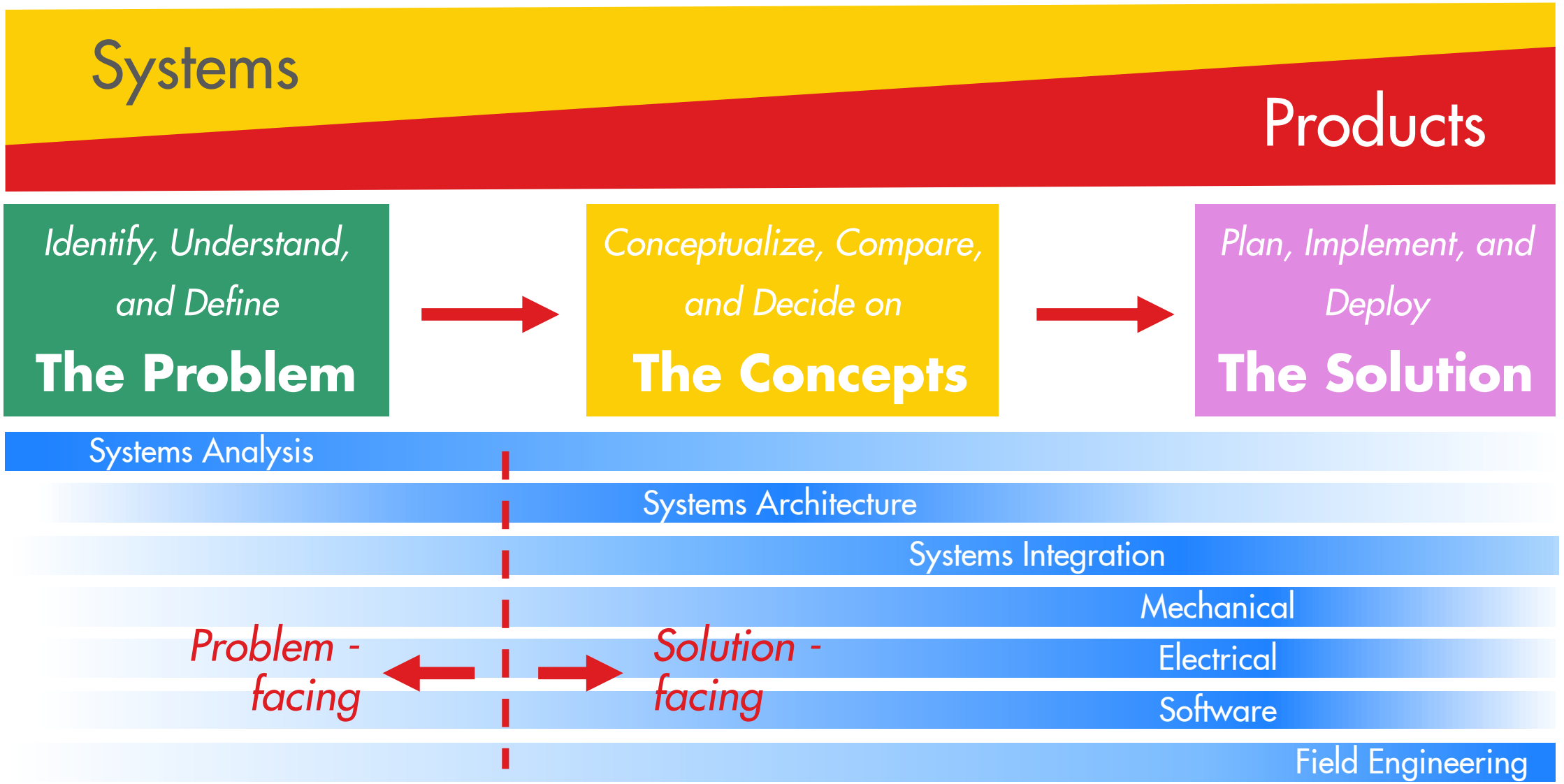
Design Thinking

- *User-focused*
- *Iterative*
- *Solution-based*



Source: Design Thinking 101, nngroup.com

Shell TechWorks



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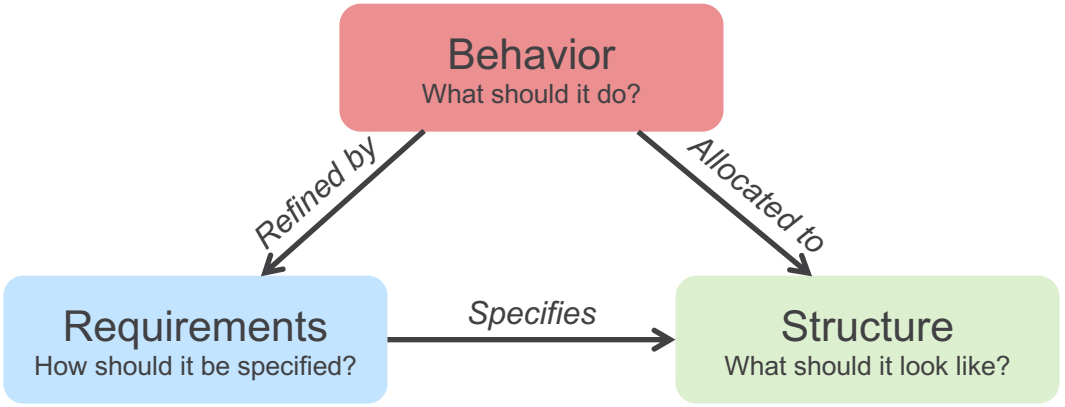

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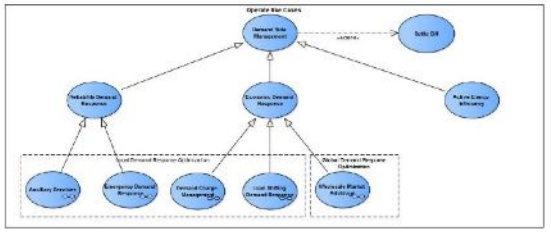
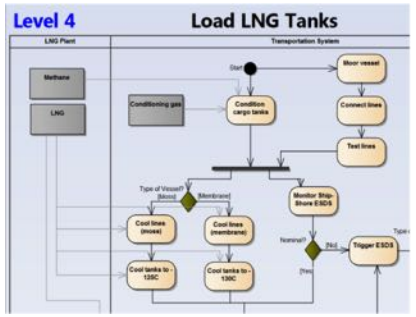
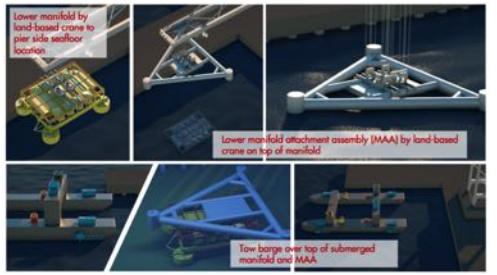




Activity diagrams detail lower level functions performed by system's subsystems



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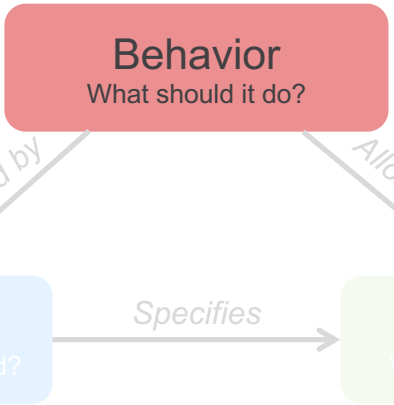

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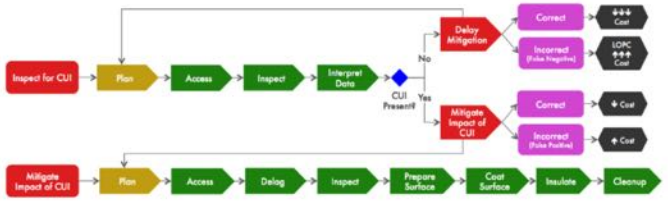

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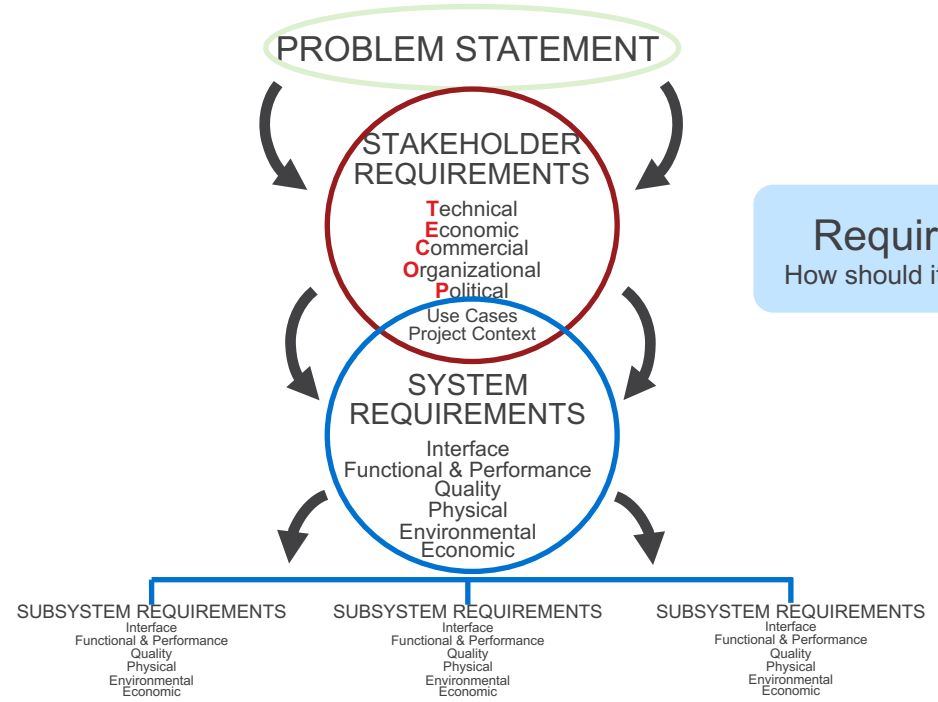

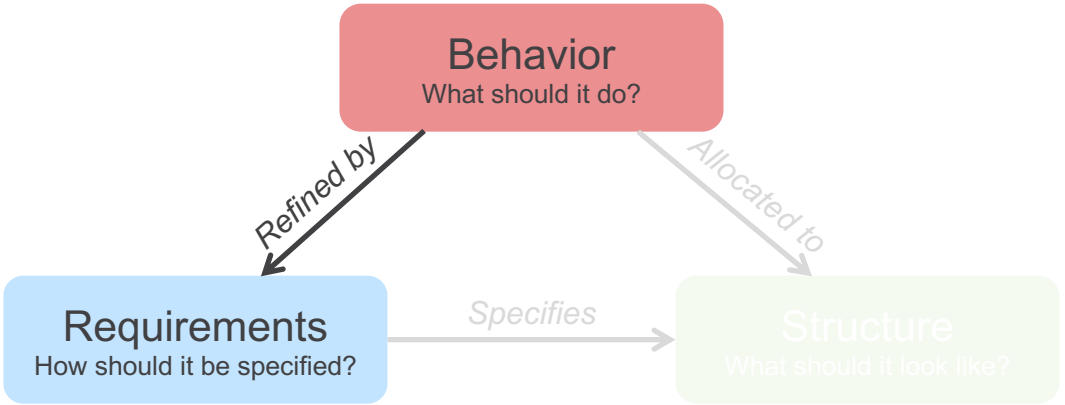

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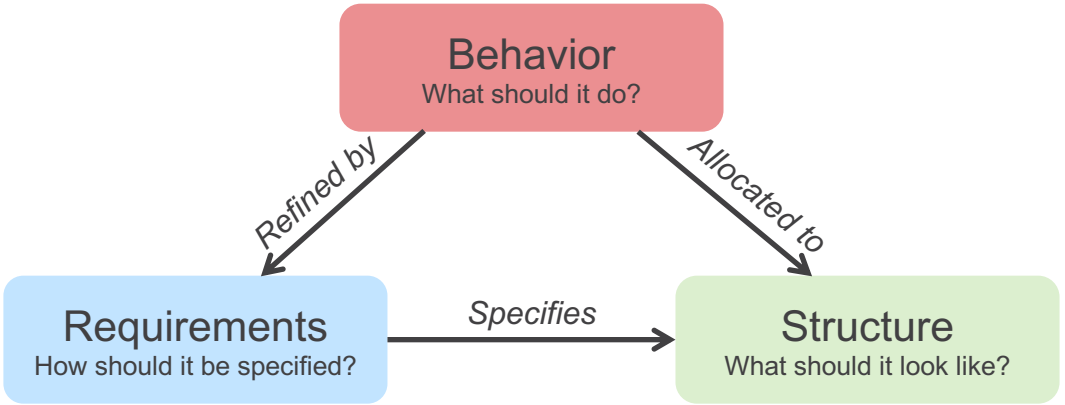
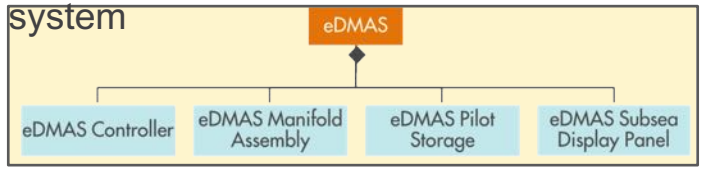
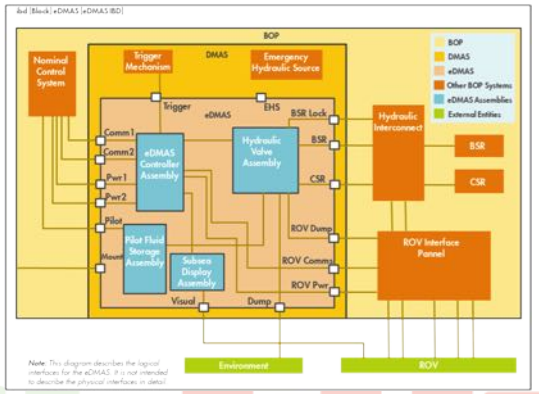


Block Definition Diagrams describe the physical, structural hierarchy of the system





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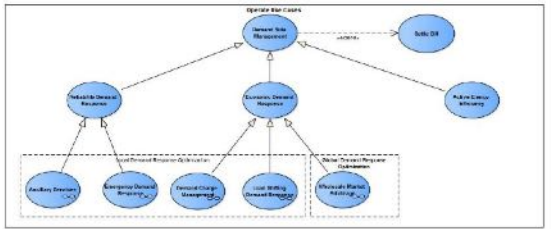

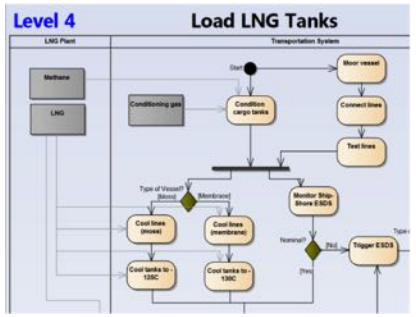

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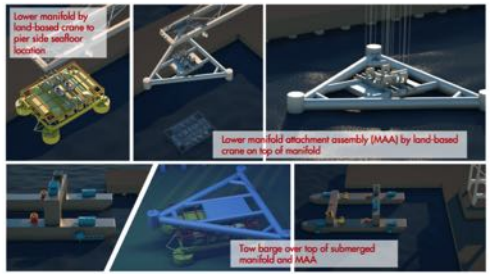

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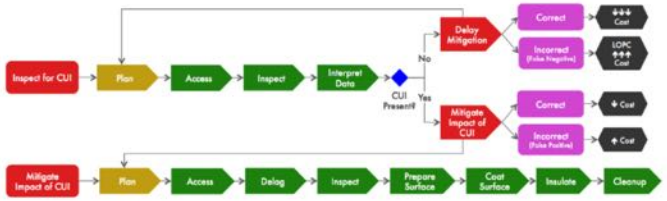

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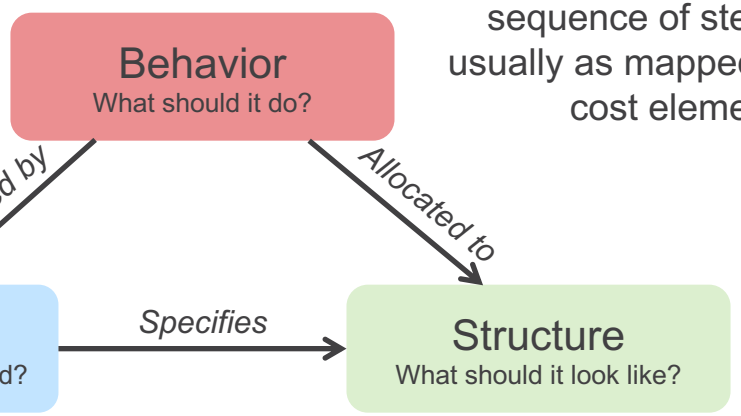

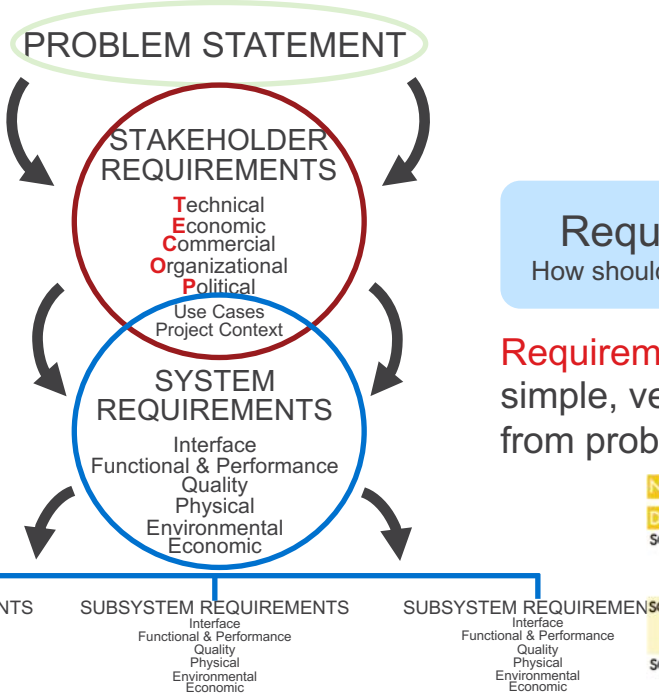

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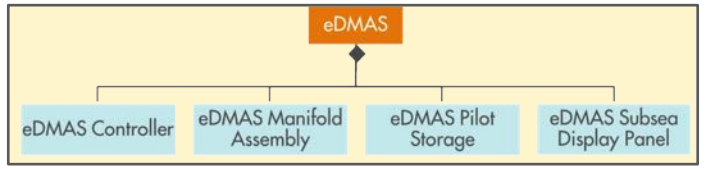

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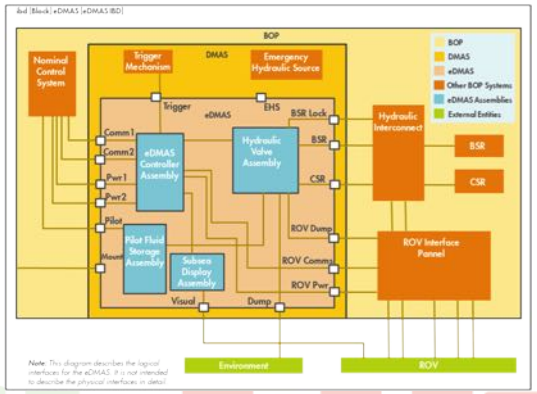

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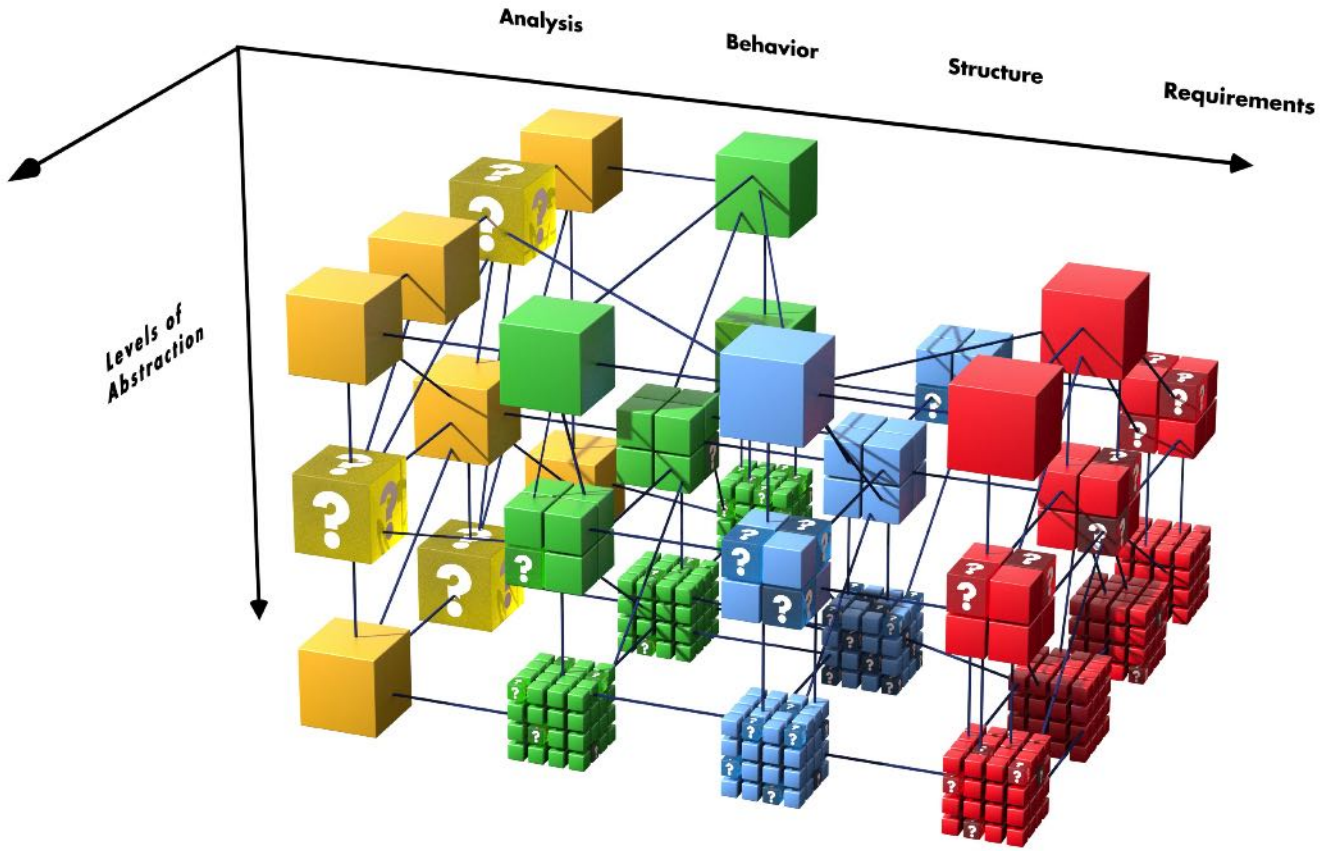
The Challenge: *How do we visualize complex systems to better understand where to target innovation?*



Influential Attribute Network Graphs

The Benefits

- Benefits to Architect
  - Reduce Ambiguity
  - Manage Complexity
  - Employ Creativity
- Bridge gap between KPI's and system design/operations
- Facilitate communication between execs and engineering team
- Cut through SME bias
- Help determine where to focus resources

Case Study 1

Subsea Well Plug & Abandonment

Purpose of Plug and Abandonment

- When wells are no longer economic to produce they must be Plugged and Abandoned.
  - Provide downhole isolation of hydrocarbon and sulphur zones
  - Protect freshwater aquifers
  - Prevent migration of formation fluids within the wellbore to the seafloor.
- Must comply with BSEE 250.1700 decommissioning regulations and Shell Standards
- Well owners are required by law to hold the liability to P&A a well for all active wells
  - Liability includes the full cost to P&A the well

The Challenge

- Project Charter:
  - Reduce Shell's P&A liability in US GoM Subsea well portfolio by 20% through technology deployment

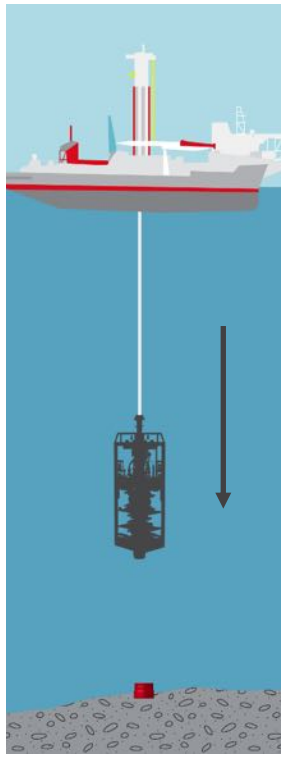
- Project Challenges:
  - Intense pressure from business to meet target
  - Project sponsor with existing funnel of technologies
  - New STW team with little wells domain knowledge
  - Constrained resources (people)
  - SME bias and risk aversion

How to P&A a Subsea Well in One slide

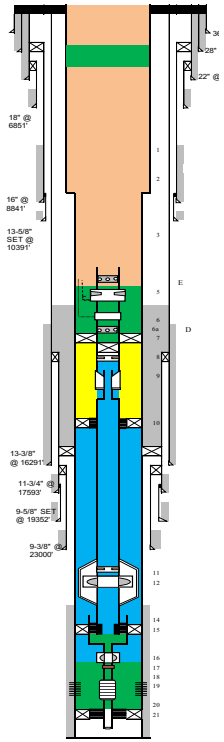
Lower Abandonment

Q4000, Intervention Riser, LMRP

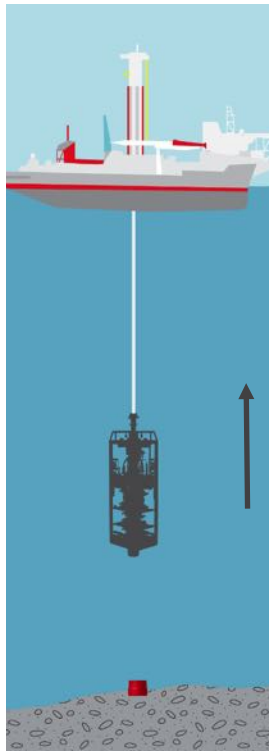
Mobilize Vessel, Deploy LMRP



Cut & Pull Tubing, Install Barriers



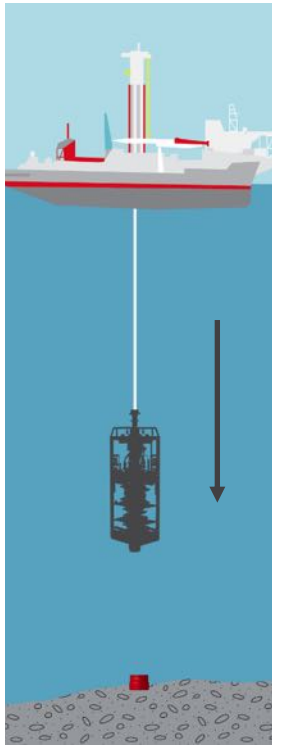
Demobilize



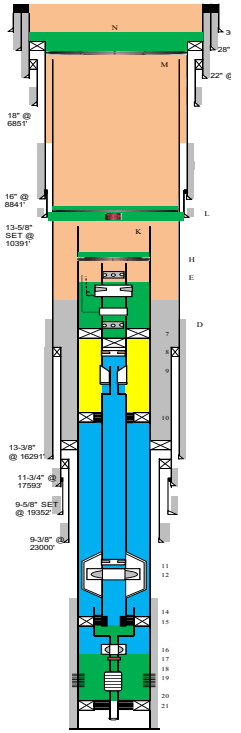
Upper Abandonment

Semi-submersible, Drilling Riser, BOP

Mobilize Vessel, Deploy BOP



Cut and Pull Casing, Install Barriers



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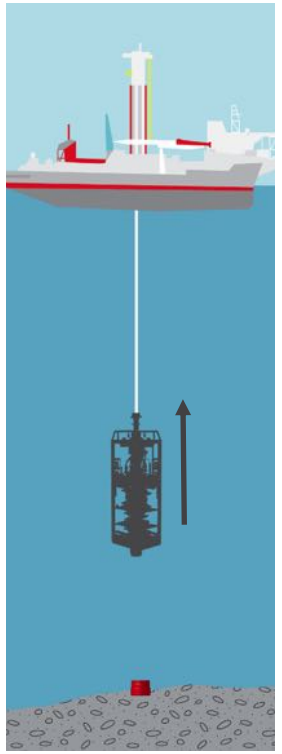
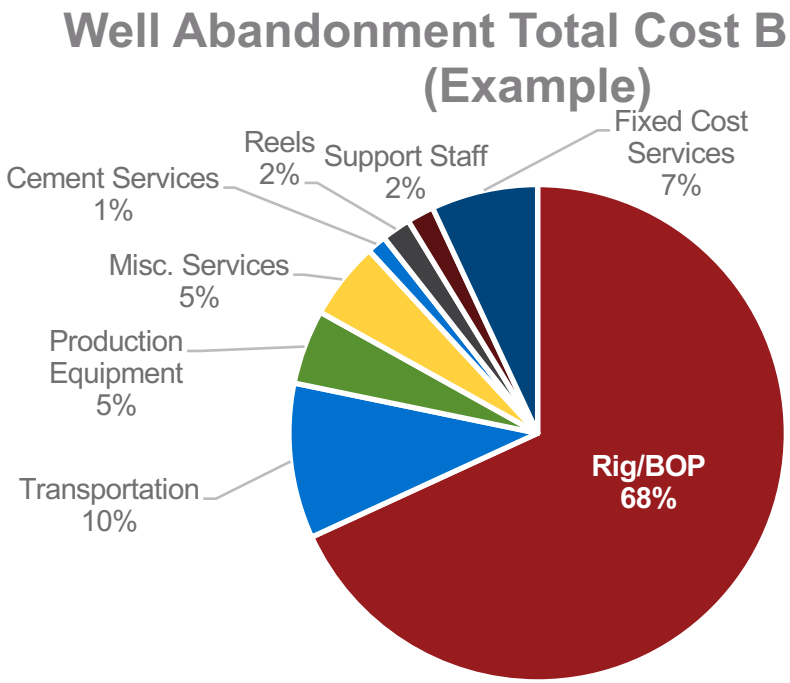
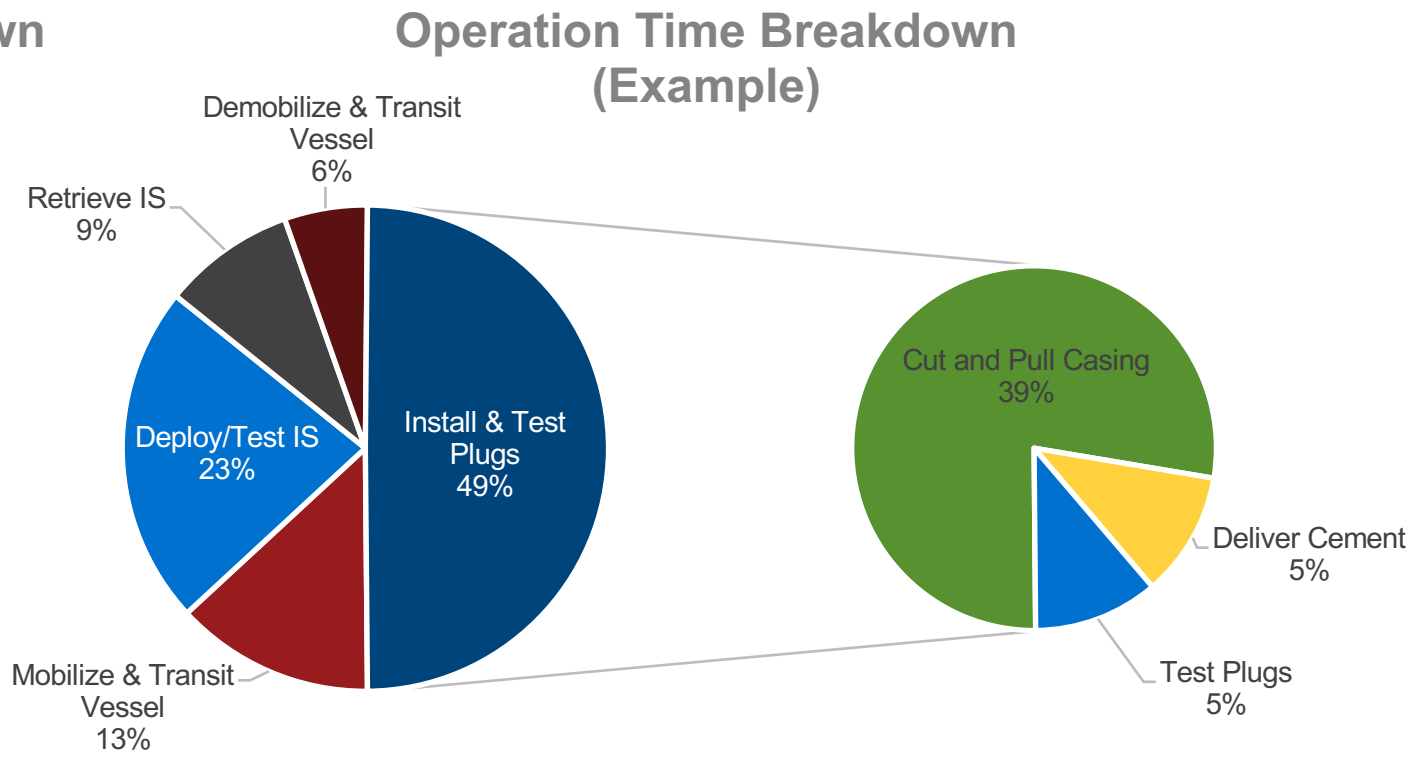
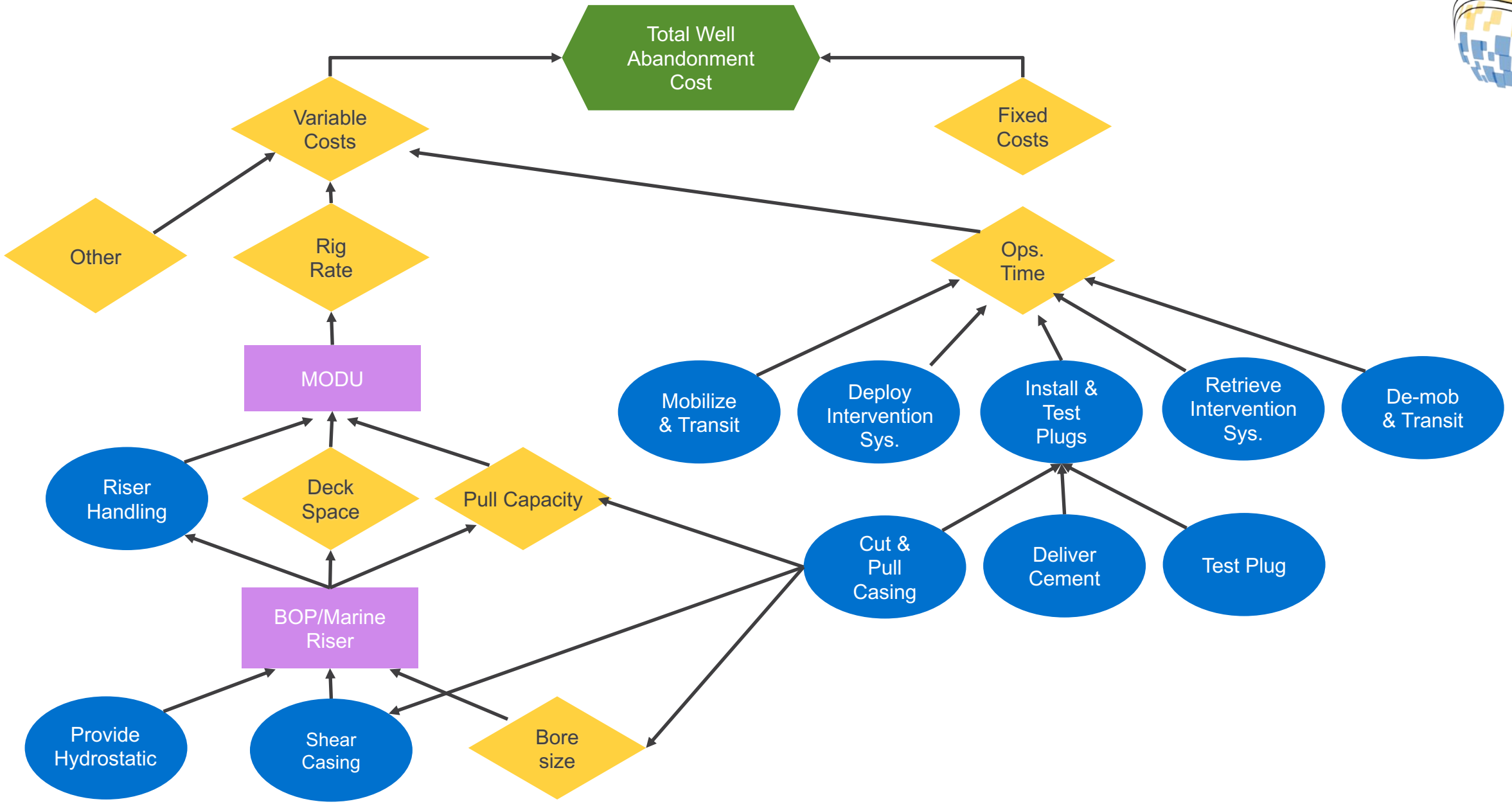


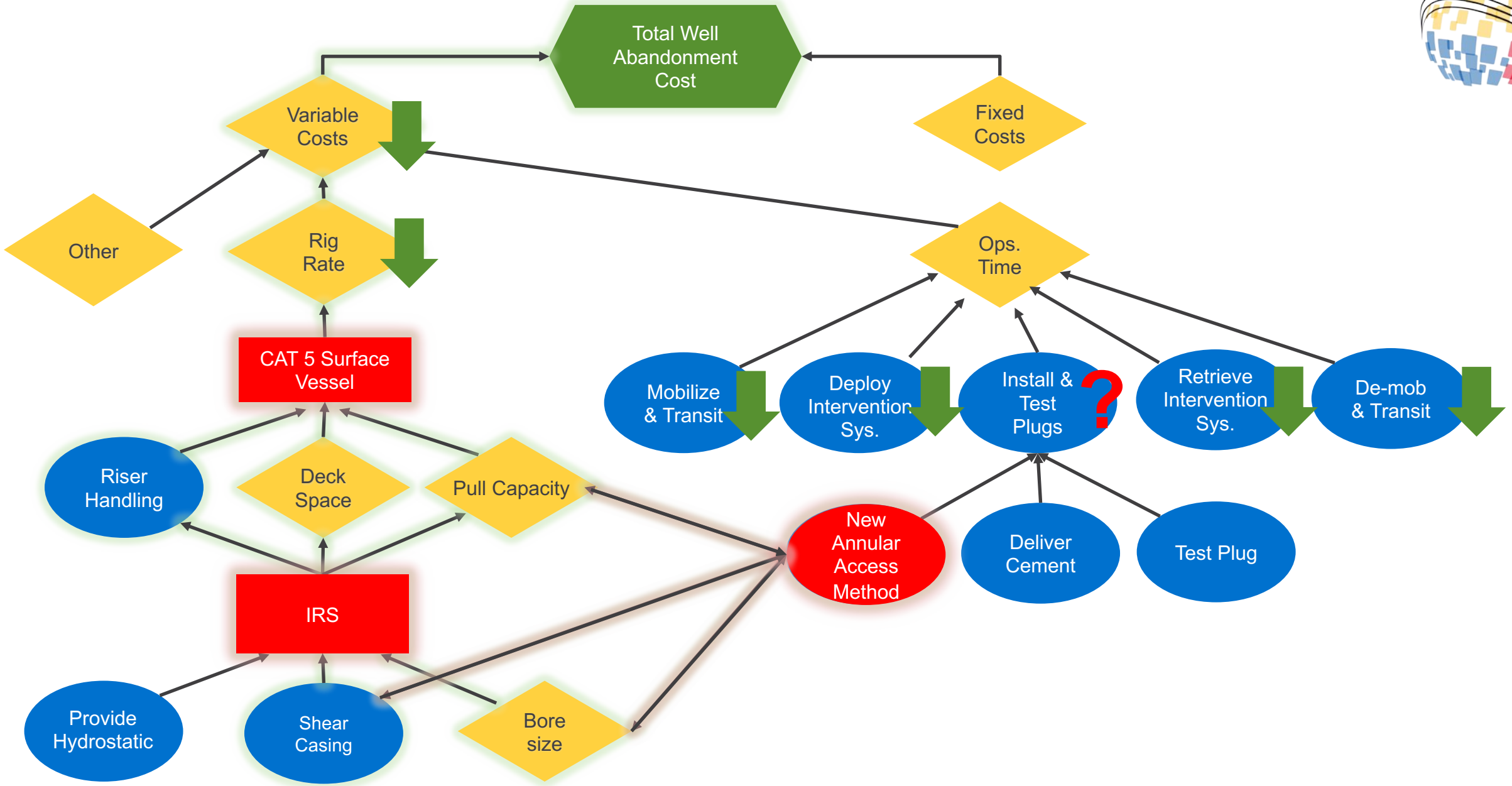
Well Abandonment Cost Breakdown





Making a step change decrease in costs requires addressing the RIG/BOP costs.


Total Well Abandonment Cost
Variable Costs
Fixed Costs
Other
Rig Rate
Ops. Time
MODU
Mobilize & Transit
Deploy Intervention Sys.
Install & Test Plugs
Retrieve Intervention Sys.
De-mob & Transit
Riser Handling
Deck Space
Pull Capacity
Cut & Pull Casing
Deliver Cement
Test Plug
BOP/Marine Riser
Provide Hydrostatic
Shear Casing
Bore size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Rig Rate
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CAT 5 Surface Vessel
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Deploy Intervention Sys.
Install & Test Plugs
Retrieve Intervention Sys.
De-mob & Transit
Riser Handling
Deck Space
Pull Capacity
New Annular Access Method
Deliver Cement
Test Plug
IRS
Provide Hydrostatic
Shear Casing
Bore size

Benefits Realized

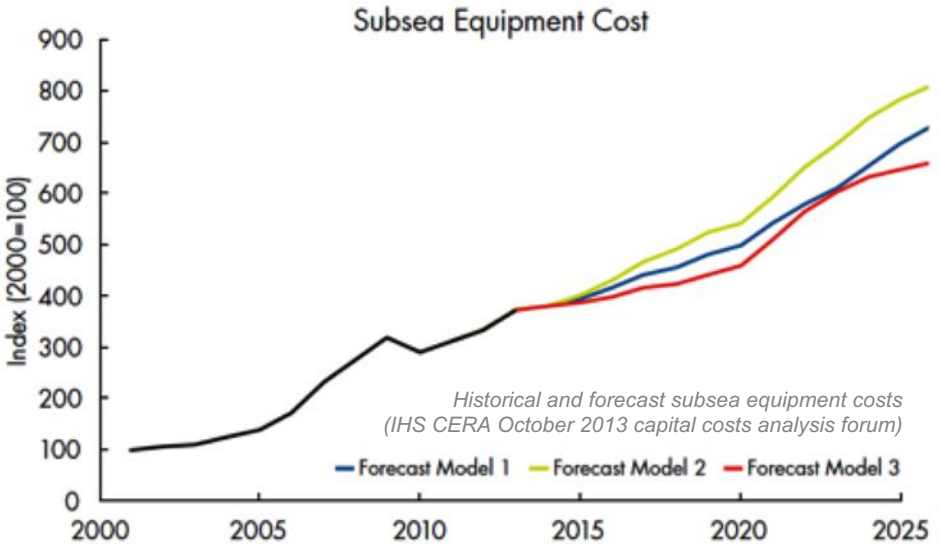
- What's important?
  - Graphs helped simplify a complex system and understand the critical factors.
  - Helped see the forest through the trees.
- Simplified communication
  - Facilitated conversation with SMEs and stakeholders
  - Bridge the gap between the highest level KPIs and system design/Operations
- Direct program resources
  - Identifies specific scope of work that directly provides value to KPI.
- Develop and assess alternatives
  - Helps team brainstorm alternatives
  - Shows how alternative solutions fit-in and impact the rest of the system

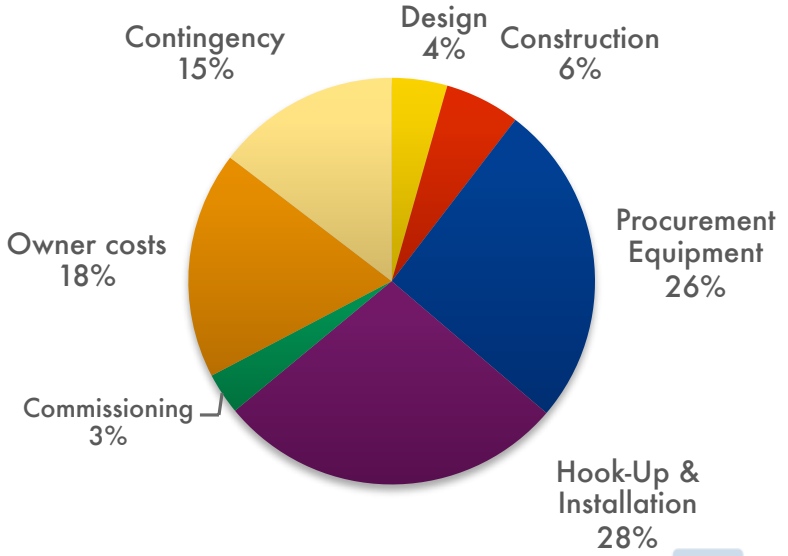
Case Study 2

Subsea Equipment Installation

The Problem

- Subsea equipment costs are rising as we develop deeper and more challenging fields
- Installation costs represent *more than ¼* of the total subsea costs of a Greenfield development project and *about 1/3* of installation costs come from construction vessel charter rates.





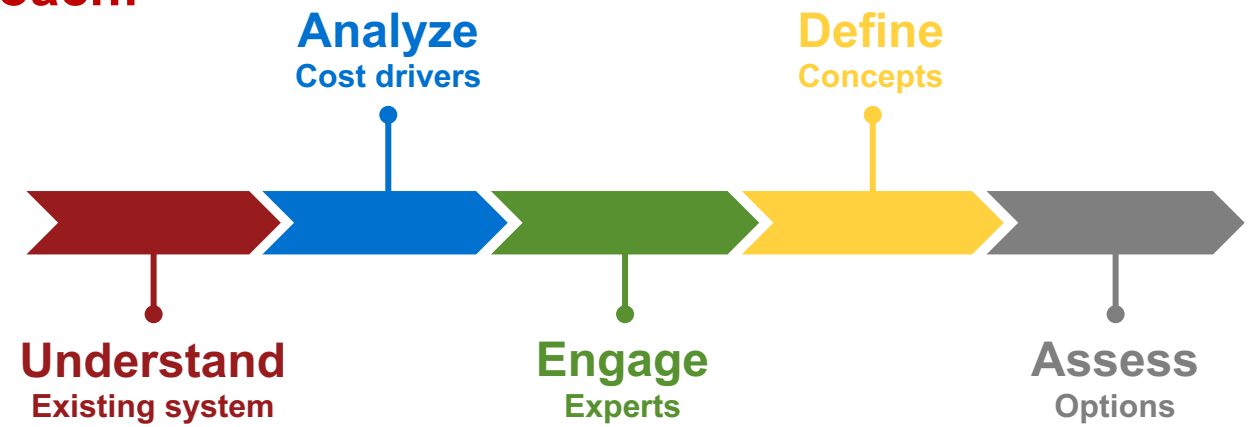
The Opportunity

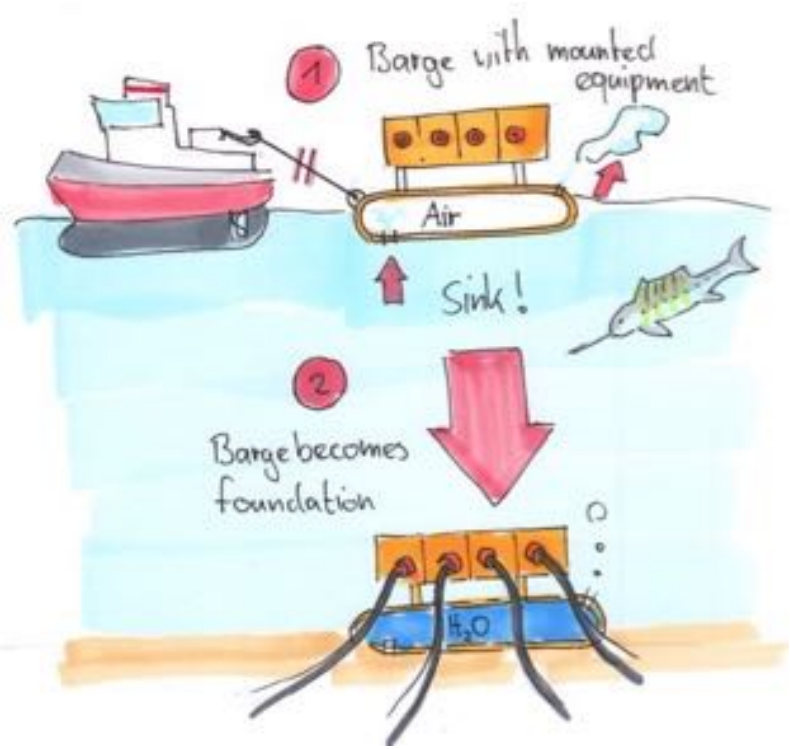
Opportunity Statement: *Subsea installation costs can be reduced by floating modules to their sites using a submersible barge towed by a smaller vessel.*

Scope:

- Focus on subsea manifold installations only
- Use data from two recent subsea field developments

Approach:





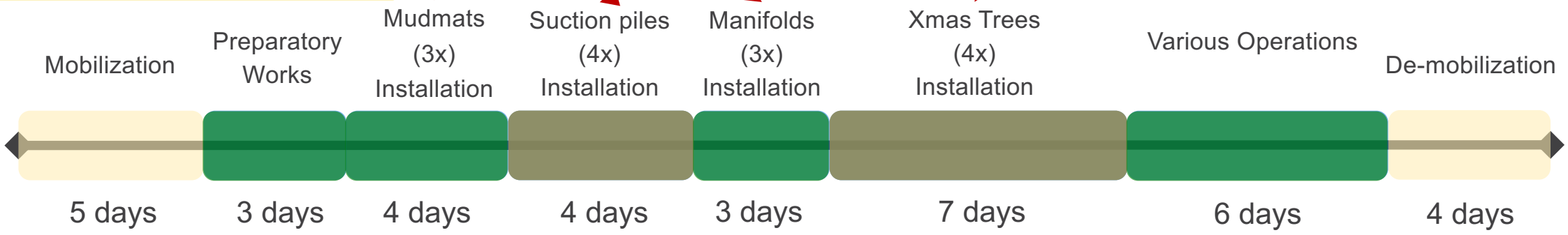
Understanding Cost Drivers

Mudmats & manifolds were installed separately, but mudmats are designed to hold the weight of the manifold so they must be installed with clump weights, which then need to be removed before manifold installation can begin.

Base Case: manifolds & mudmats
Upside: suction piles, trees, PLETs, PLEMs, jumpers, templates, SDAs, SUTAs

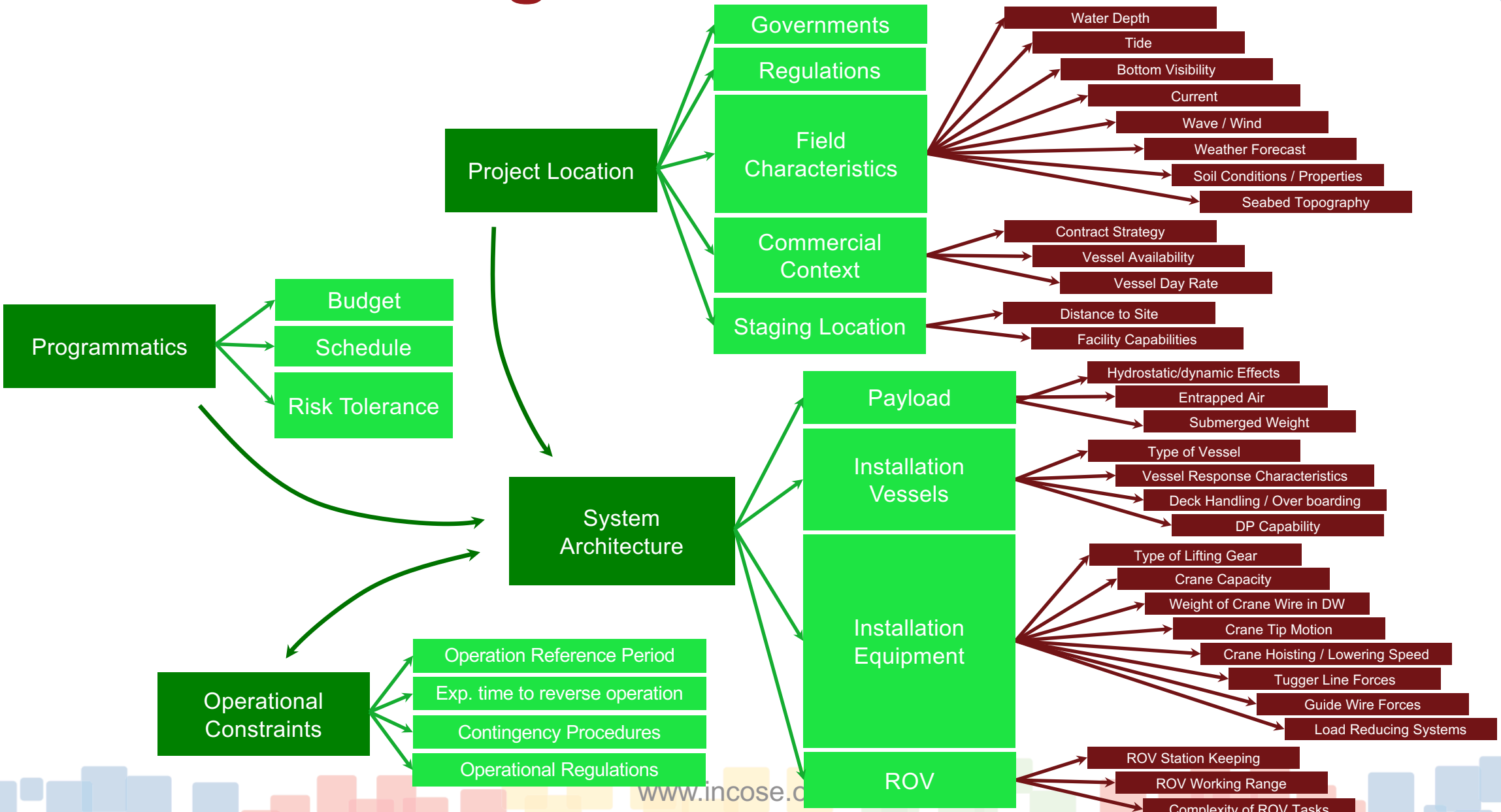
Concepts will assume mudmats and manifolds can be installed together for those concepts that offer sufficient margin on lift capacity to do so.

Concepts may be capable of installing other structures like piles and trees but for the scope of this study, only manifolds are considered.

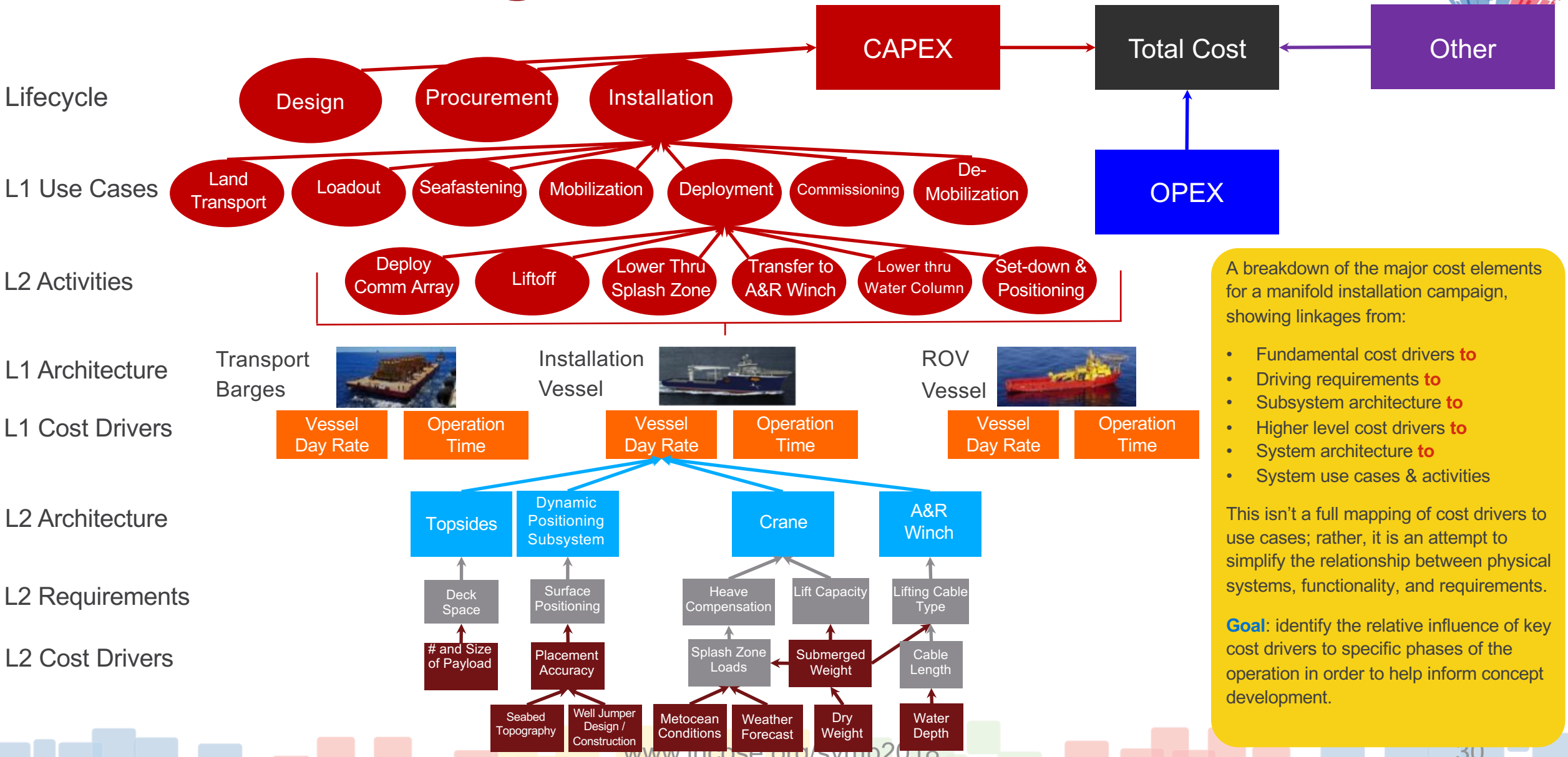


Vessel Type	Total Installation Time	Subtracted Installation Time for Piles + Trees	Manifold Installation Time for Base Estimate	Mob / De-mob Time
Heavy Lift Vessel	27 days	11 days	16 days	9 days

Understanding Cost Drivers



Understanding Cost Drivers



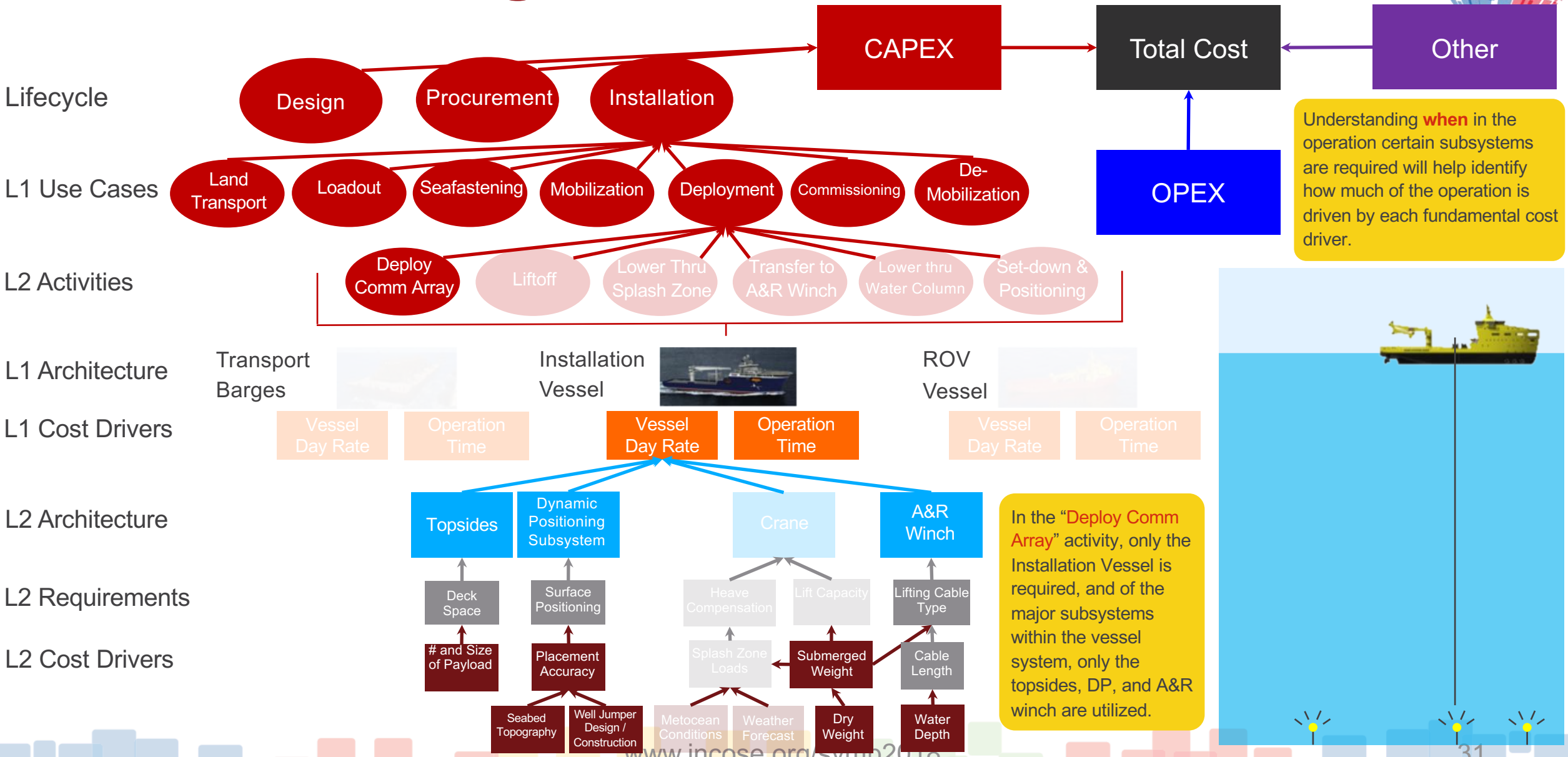
A breakdown of the major cost elements for a manifold installation campaign, showing linkages from:

- Fundamental cost drivers **to**
- Driving requirements **to**
- Subsystem architecture **to**
- Higher level cost drivers **to**
- System architecture **to**
- System use cases & activities

This isn't a full mapping of cost drivers to use cases; rather, it is an attempt to simplify the relationship between physical systems, functionality, and requirements.

Goal: identify the relative influence of key cost drivers to specific phases of the operation in order to help inform concept development.

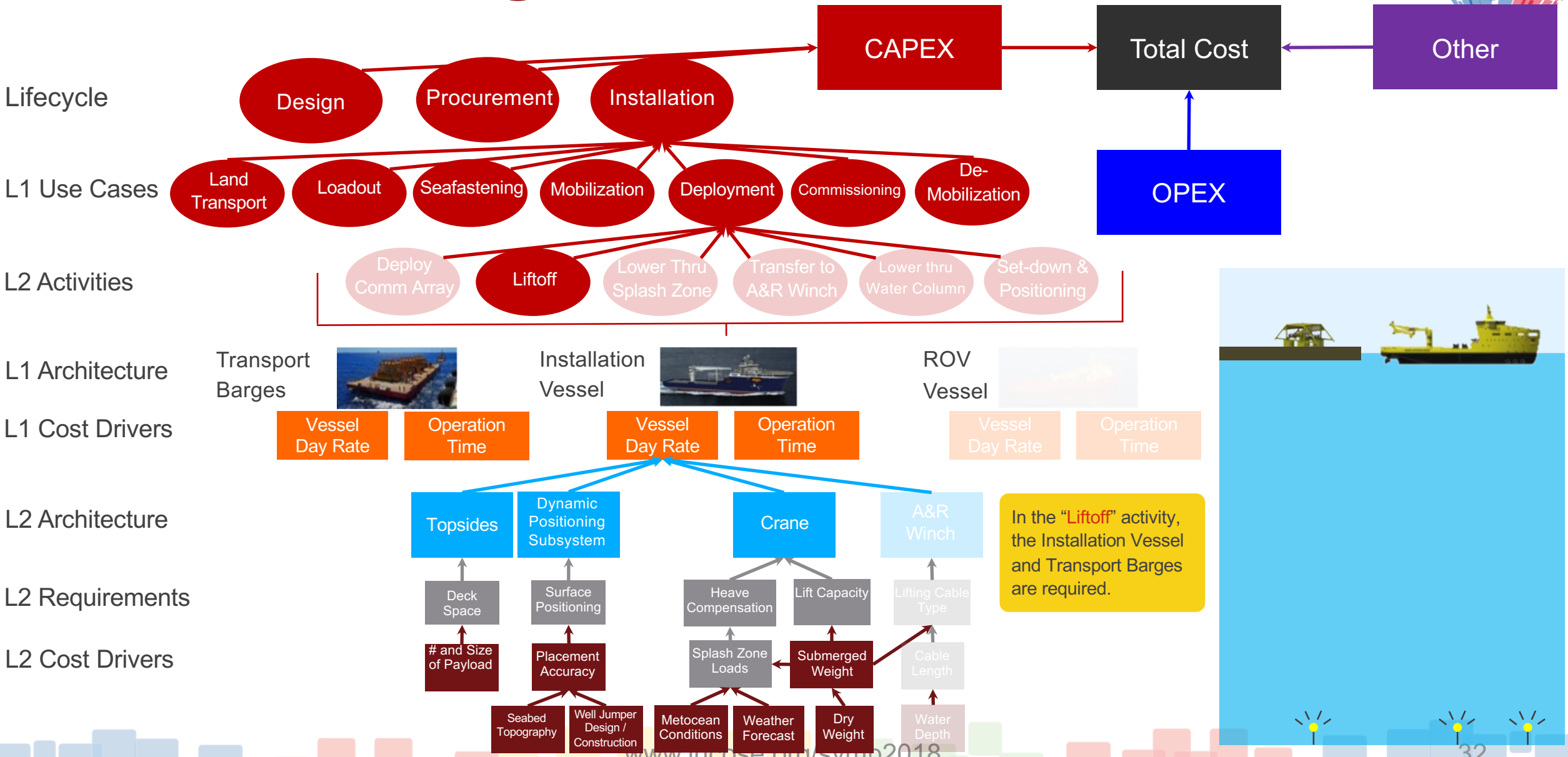
Understanding Cost Drivers



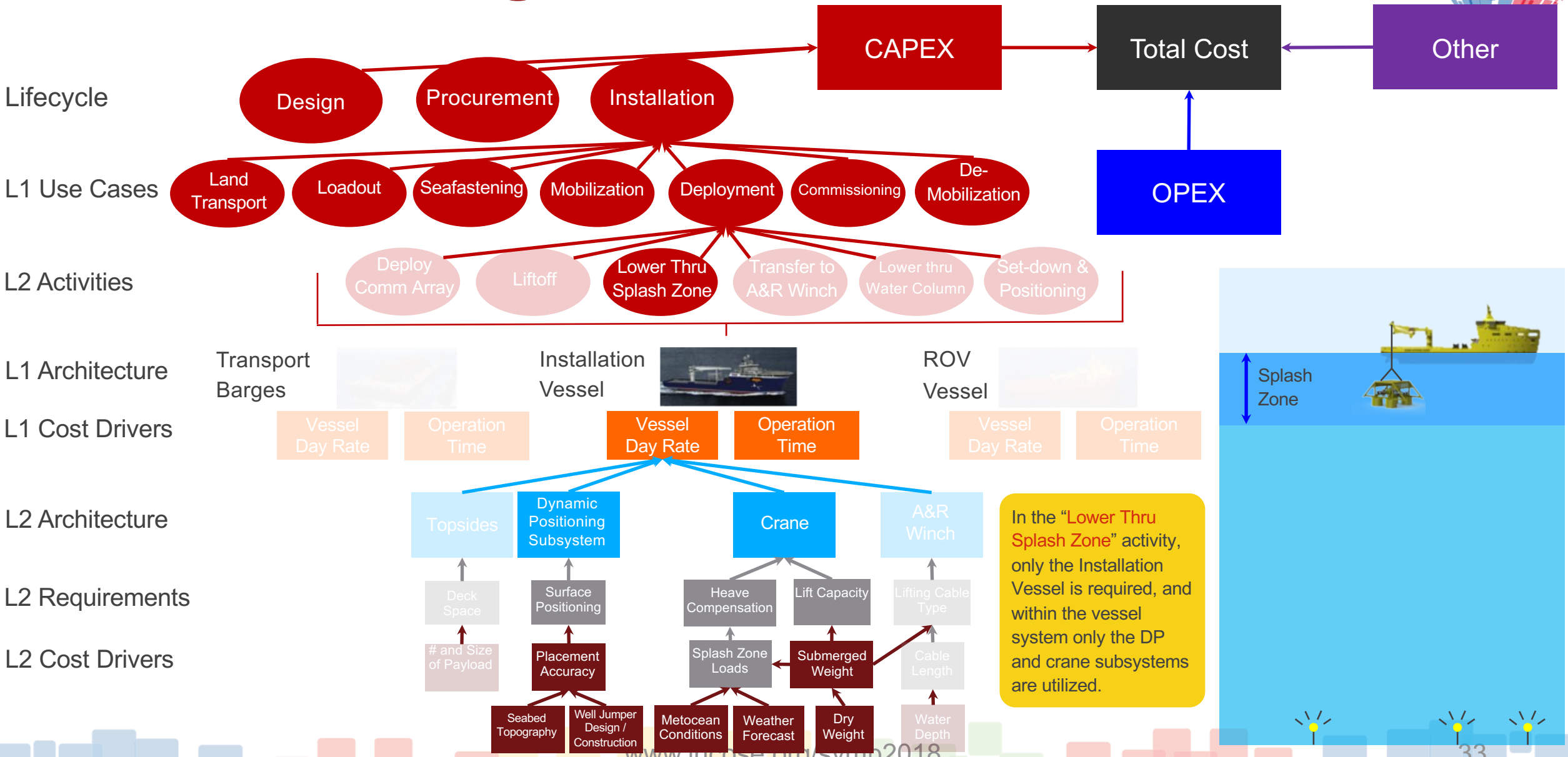
Understanding **when** in the operation certain subsystems are required will help identify how much of the operation is driven by each fundamental cost driver.

In the "Deploy Comm Array" activity, only the Installation Vessel is required, and of the major subsystems within the vessel system, only the topsides, DP, and A&R winch are utilized.

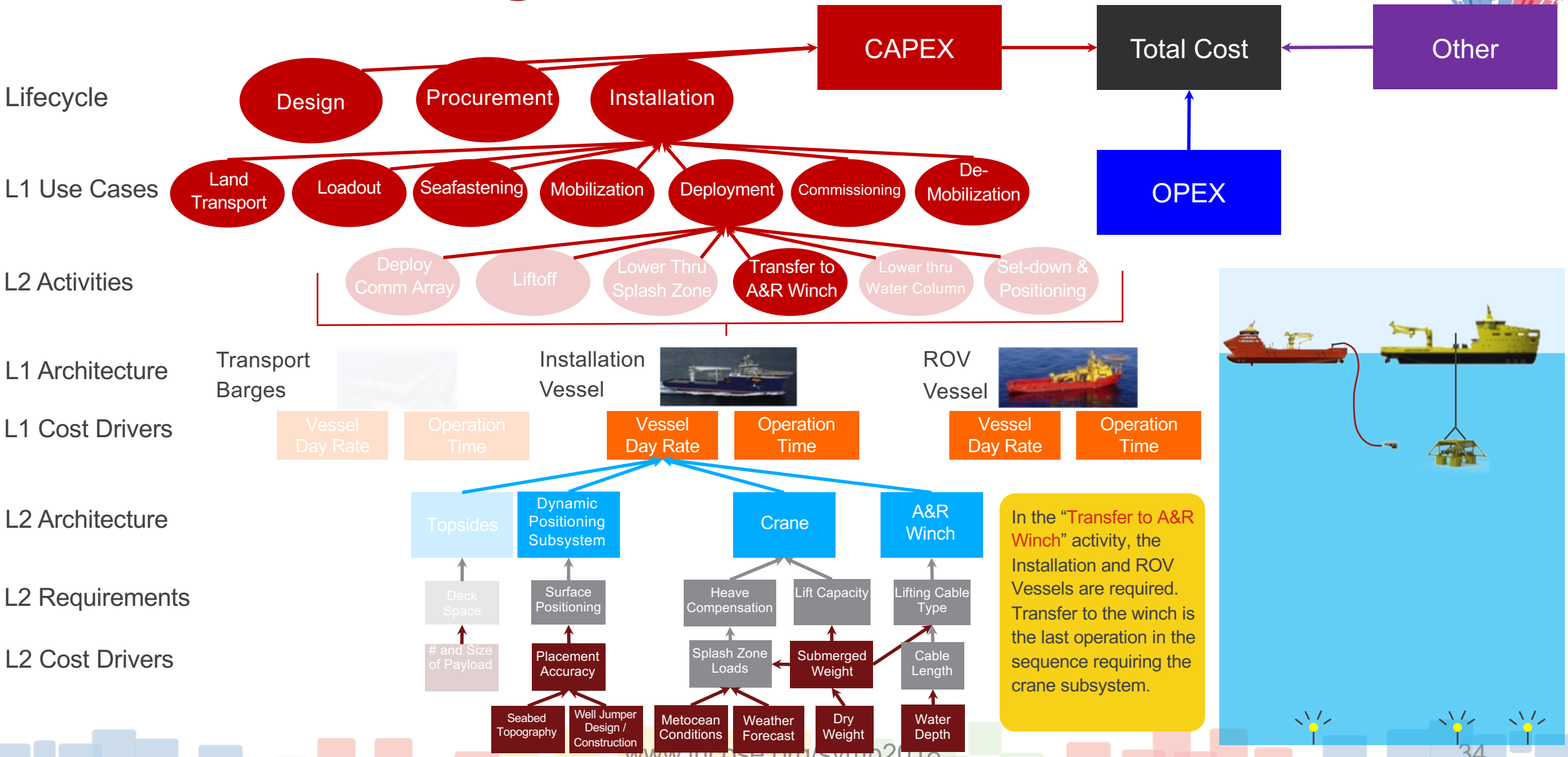
Understanding Cost Drivers



Understanding Cost Drivers

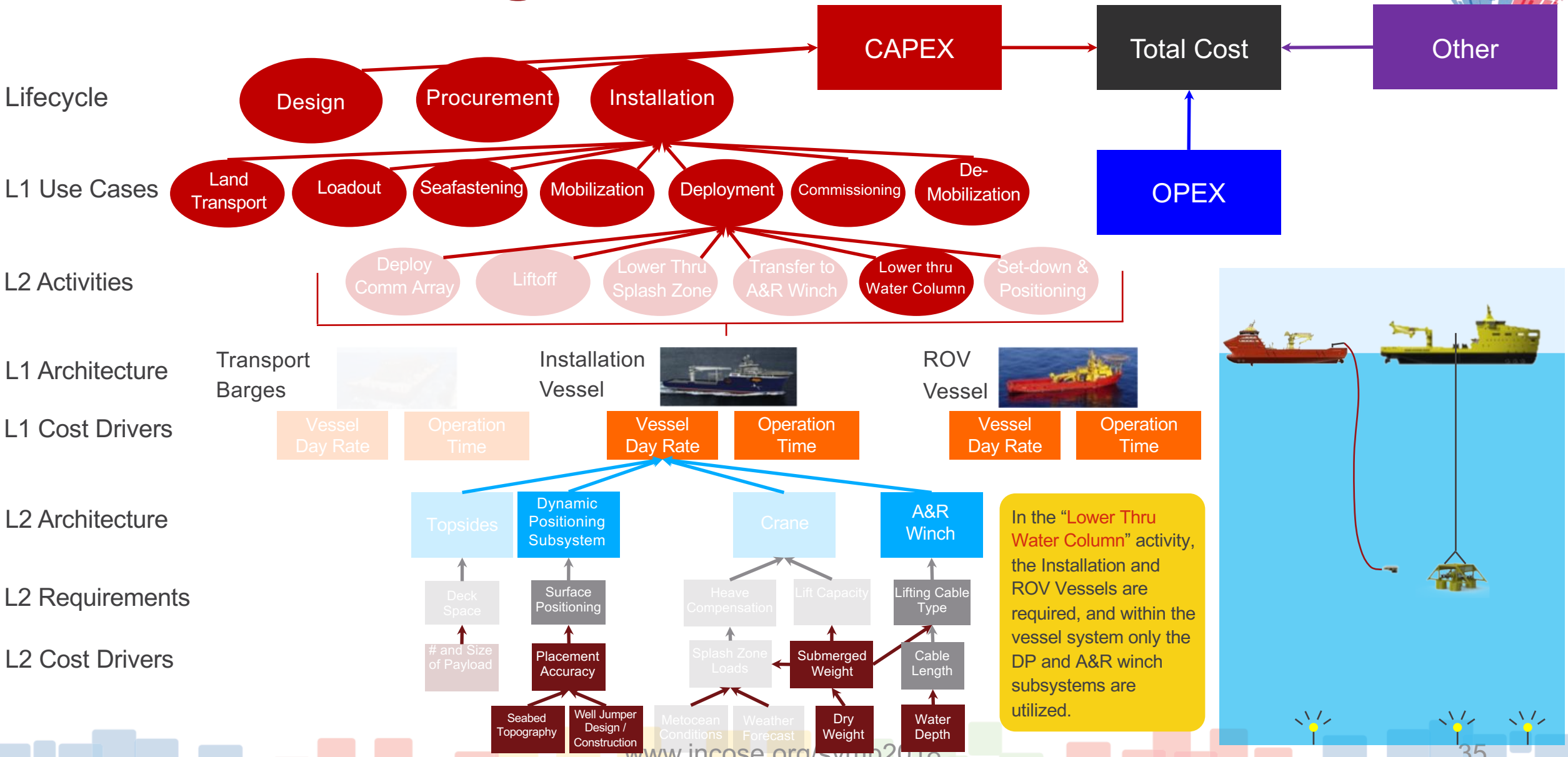


Understanding Cost Drivers

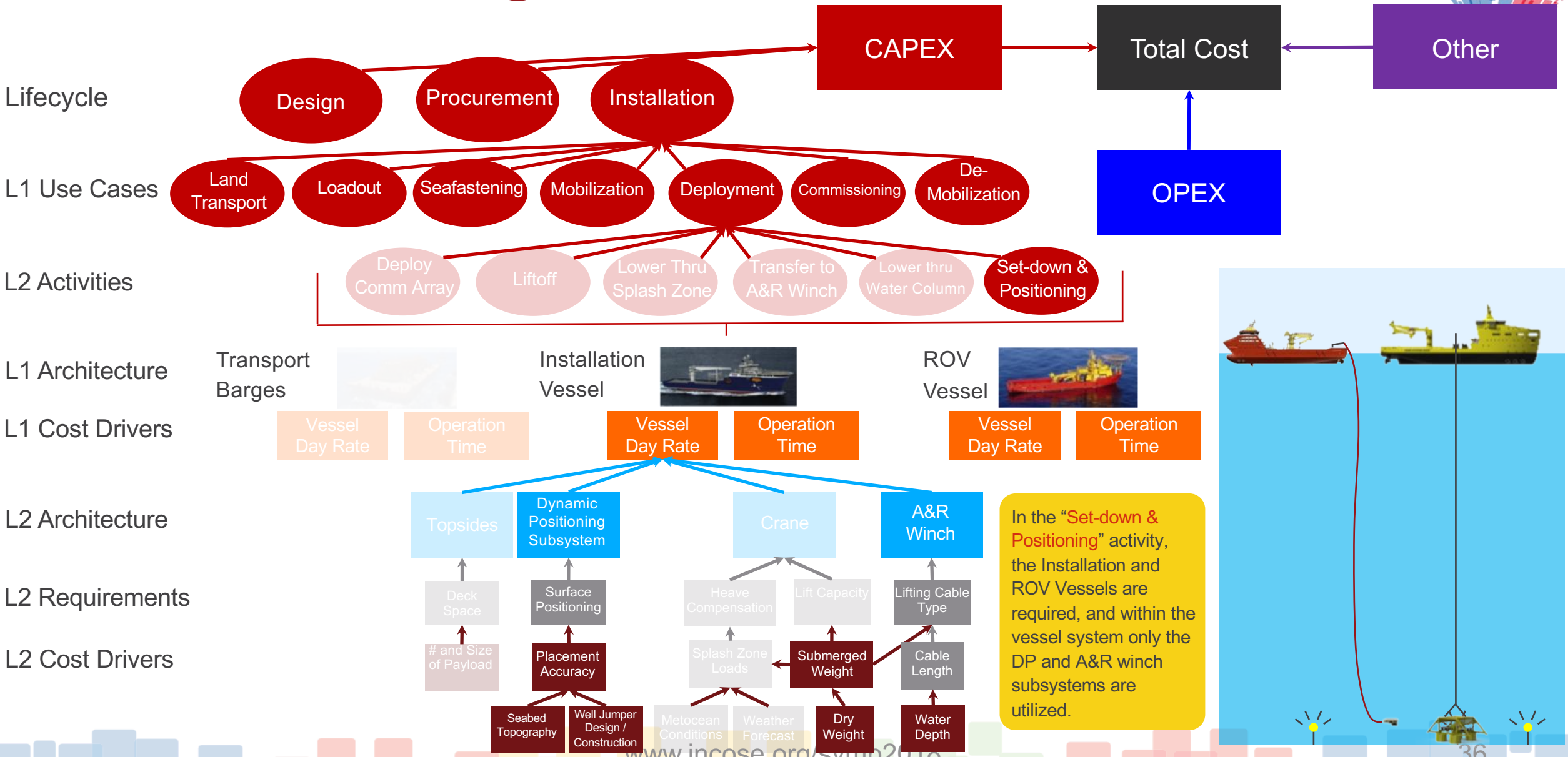


In the "Transfer to A&R Winch" activity, the Installation and ROV Vessels are required. Transfer to the winch is the last operation in the sequence requiring the crane subsystem.

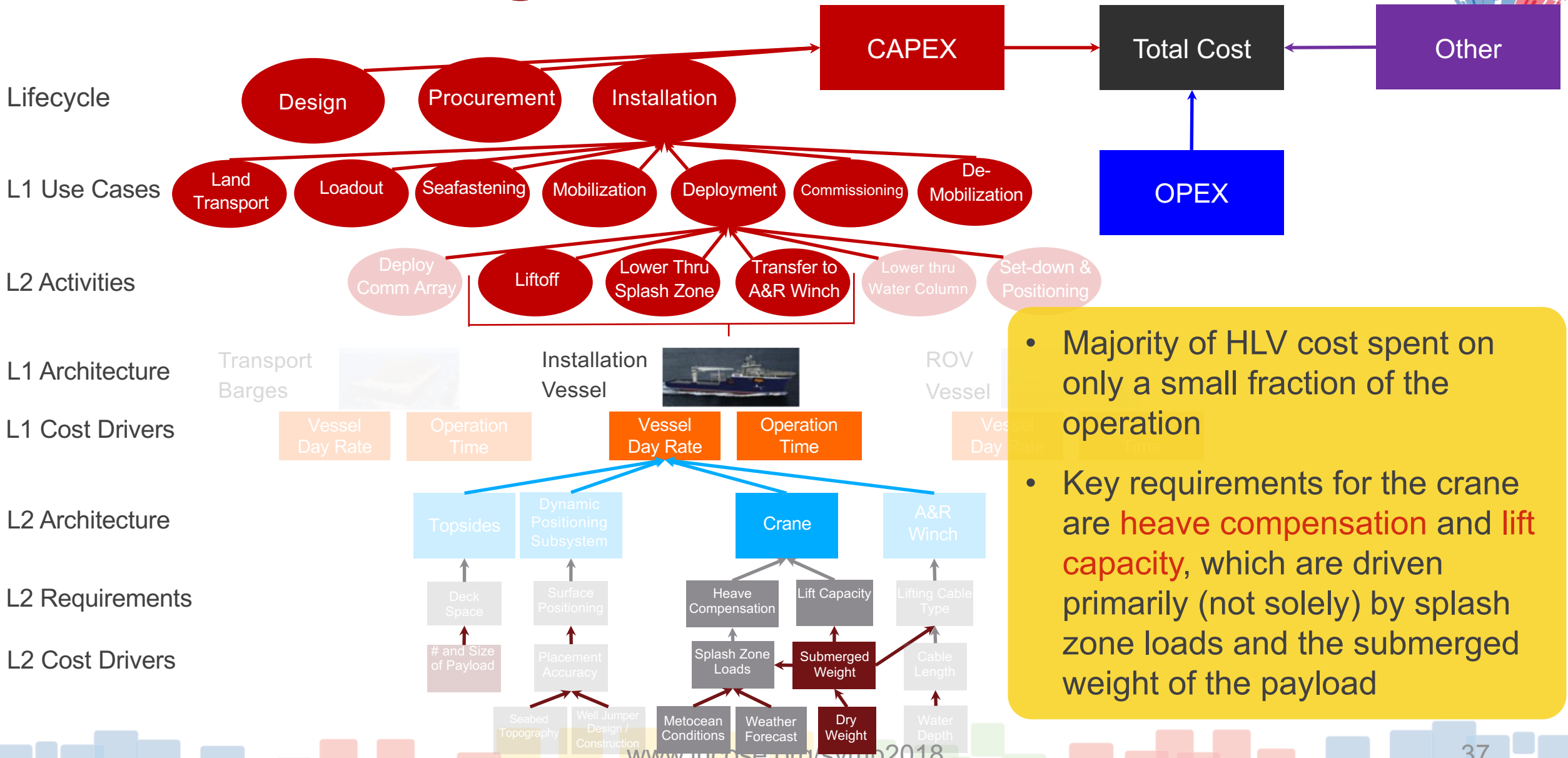
Understanding Cost Drivers



Understanding Cost Drivers

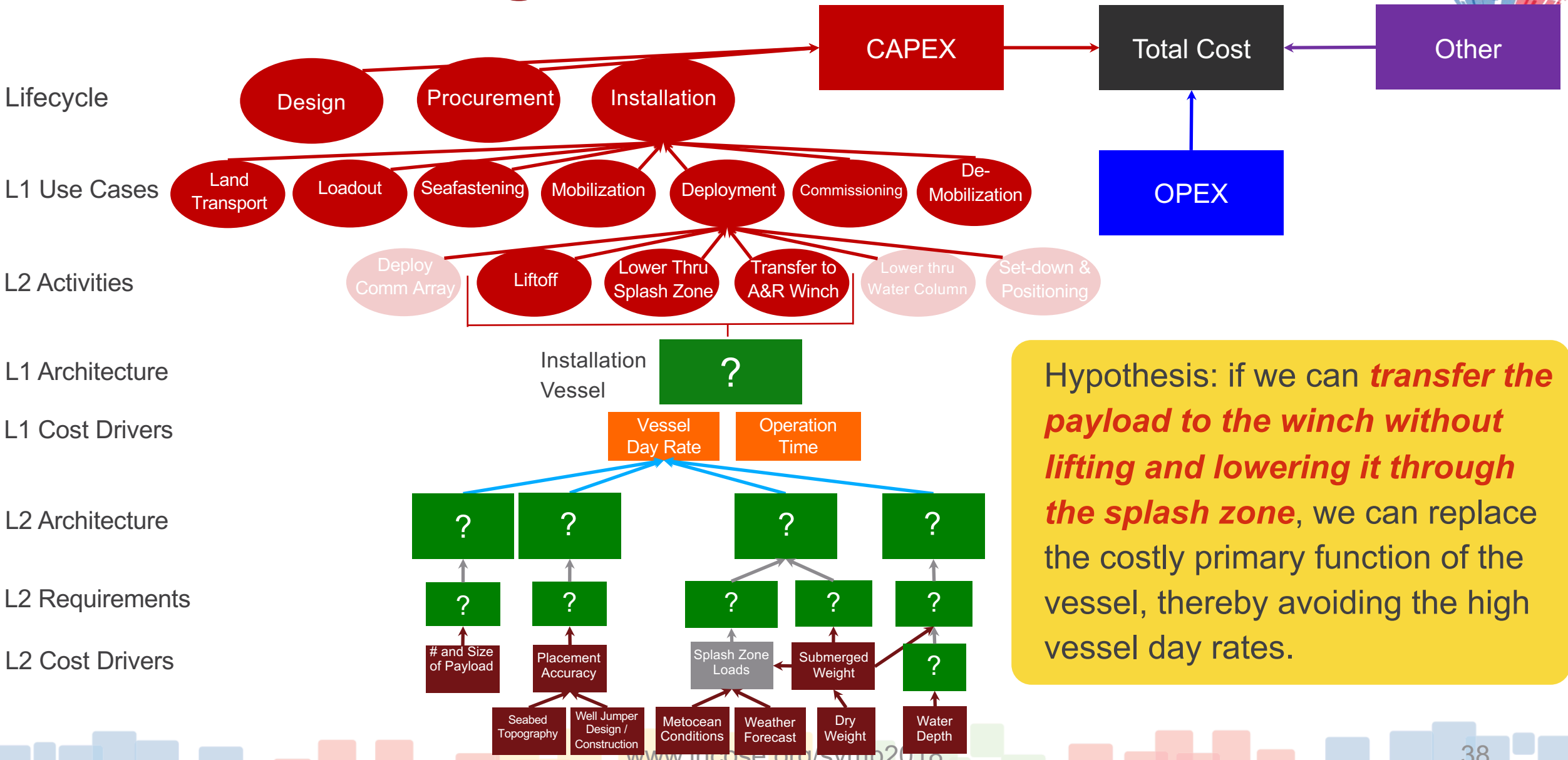


Understanding Cost Drivers



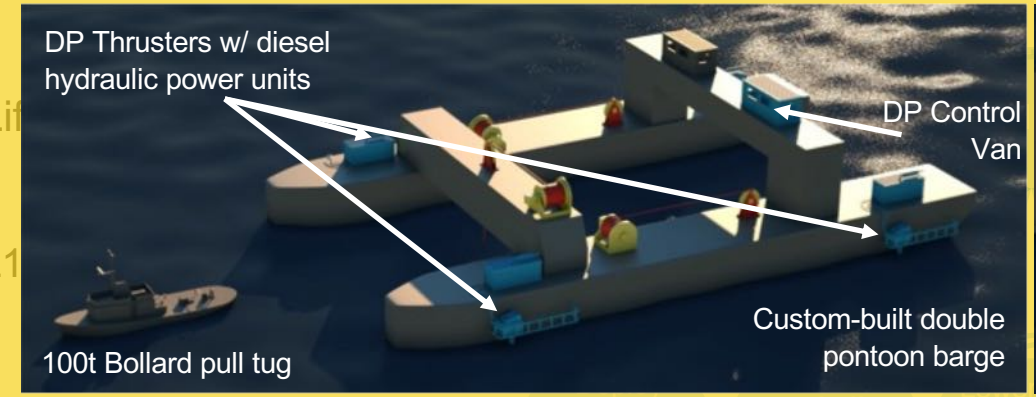
- Majority of HLV cost spent on only a small fraction of the operation
- Key requirements for the crane are heave compensation and lift capacity, which are driven primarily (not solely) by splash zone loads and the submerged weight of the payload

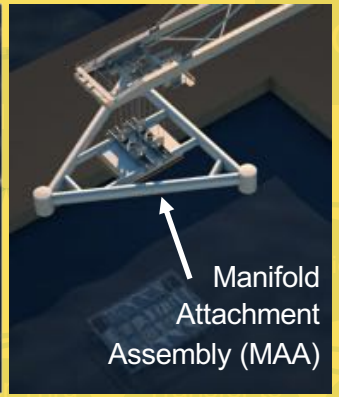
Understanding Cost Drivers

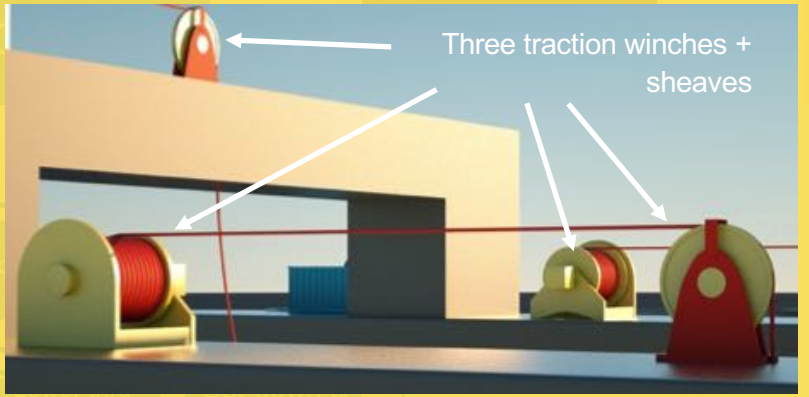


Hypothesis: if we can ***transfer the payload to the winch without lifting and lowering it through the splash zone***, we can replace the costly primary function of the vessel, thereby avoiding the high vessel day rates.

Concept Definition







L2 Activities

L1 Architecture

Custom Barge Delivery System

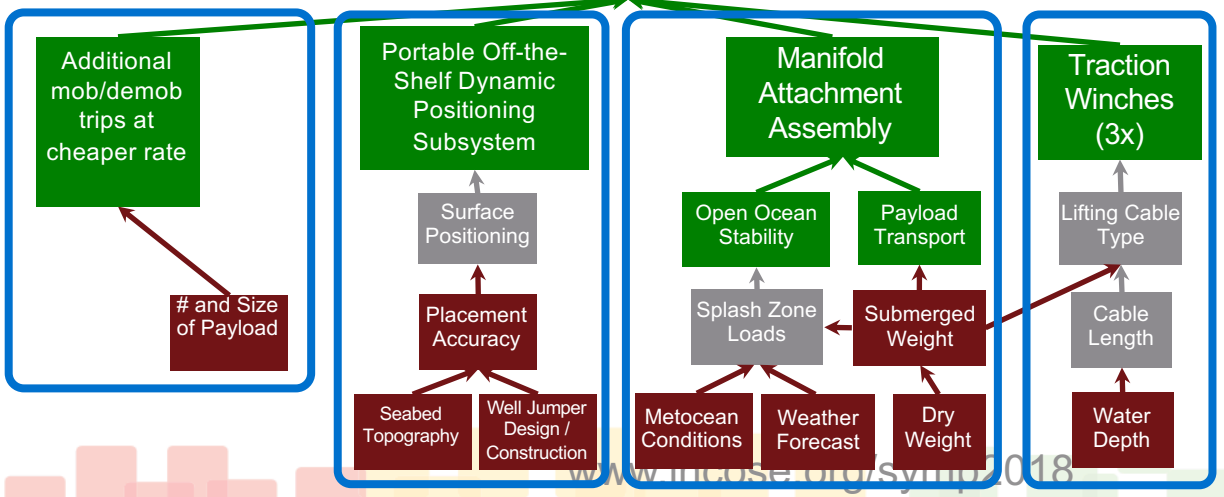
ROV Vessel

L1 Cost Drivers

Vessel Day Rate | Operation Time

Vessel Day Rate | Operation

L2 Architecture



L2 Requirements

L2 Cost Drivers

Concept Features:

- Lower charter rate means deck space is no longer a factor since it is now economical to make individual mob/demob trips for each payload
- A portable, off-the-shelf dynamic positioning system can be installed on the barge for a fraction of the cost of outfitting an entire HLV
- In place of a crane, a manifold attachment assembly serves as the interface between the barge and payload, provides stability during operations and transport, and alleviates splash zone loads
- Three traction winches take the place of the A&R winch, meaning the capacity of each winch can be reduced while providing redundancy

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